Universidade de Aveiro Departamento de Biologia
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Selecção de *habitat* por carnívoros na Serra do Bussaco

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Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Biologia Aplicada, ramo de Ecologia, Biodiversidade e Gestão de Ecossistemas, realizada sob a orientação científica do Doutor Carlos Manuel Martins Santos Fonseca, Professor Auxiliar com Agregação do Departamento de Biologia da Universidade de Aveiro

Aos bichos, que não têm culpa nenhuma.

o júri

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palavras-chave

Foto-armadilhagem, fragmentação de *habitat*, selecção de *habitat*, carnívoros simpátricos

resumo

A selecção de habitat promove a coexistência de espécies do mesmo nível trófico. Paralelamente, a destruição de habitat é tida como um fenómeno fulcral na redução da biodiversidade. Perceber os padrões de selecção de *habitat* das espécies e a eficácia desses *habitats*, permite reformular medidas de intervenção e gestão das áreas de interveniência humana. Desta forma, o presente trabalho propõe-se a avaliar a selecção de *habitat* por parte de três espécies de carnívoros simpátricos, num meio fragmentado, recorrendo a técnicas de foto-armadilhagem. Toda a temática envolve a discussão sobre o efeito das plantações de monoculturas com fins industriais e de outras áreas de intervenção humana na comunidade de carnívoros, e a discussão sobre o efeito da complexidade da paisagem na coexistência e relação interespecífica da raposa (*Vulpes vulpes*), gineta (*Genetta genetta*) e fuinha (*Martes foina*). Os resultados demonstram que as espécies em estudo demonstram padrões de selecção de habitat distintos respondendo a factores como disponibilidade de recursos e configuração da vegetação. No fim do estudo, não se pode afirmar que a fragmentação de habitat e as extensões de monoculturas patentes na área de estudo, se tenham mostrado prejudiciais para a comunidade de carnívoros estudada. No entanto a preservação de certos aspectos paisagísticos e da vegetação (eg. tamanho das parcelas de terreno, manutenção de matos nos eucaliptais) mostraram ser importantes para as espécies

keywords

Camera-trapping, habitat fragmentation, habitat selection, sympatric carnivores

abstract

Habitat selection promotes species coexistence in the same trophic level. In parallel, habitat destruction is regarded as a central phenomenon to the reduction of biodiversity. Understanding the patterns of habitat selection of the species and the effectiveness of these habitats permits to reformulate management measures of the areas with human intervention. In this way, this work proposes to evaluate the habitat selection by three sympatric carnivores' species in a fragmented landscape, using camera-trapping techniques. The whole issue involves the discussion of the effect of monocultural plantations with industrial propose and other areas of human intervention in the community of carnivores and the discussion of the effect of landscape complexity on coexistence and interspecific relationship of the fox (*Vulpes vulpes*), common genet (*Genetta genetta*) and stone marten (*Martes foina*). The results showed that species use the available habitats differently, selecting according to the resources' availability and the lay of vegetation. From a conservationist perspective, we cannot affirm that habitat fragmentation and monocultural exploitations are presenting negative effects over the studied carnivore community. However the preservation of certain aspects of the landscape and vegetation (eg. size of the parcels of land, maintenance of shrubs in eucalyptus' stands) showed to be important for the species.

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1. General introduction

Habitat selection can be described as a living beings' behavior and one of the main relationships which allows species to coexist (Rosenzweig, 1981). Differential habitat selection results in a crucial factor allowing sympatry, as it partly derives from competition and predation, stabilizing both and acting as an optimal-foraging process (Rosenzweig, 1991) or resource partitioning (Schoener, 1974). Related species differ in habitat exploitation based on specialized ways they have of using resources (McArthur and Levins, 1964). Animals that occupy the same trophic level should present a scattered distribution among the environment that supplies their ecological requirements. In this way, from an ecological and conservationist perspective, it is significant to study habitat selection patterns of sympatric populations, namely of carnivores.

Habitat fragmentation implies several phenomena that include not only the reduction of habitat amount (habitat loss) but also the increase in the number of habitat patches, the decrease in habitat patches' size and the augment of patches' isolation (Fahrig, 2003) that necessarily changes the properties of the primeval fragmented habitat (van den Berg et al., 2001). This mutation can bring some negative effects, such as the tragic reduction of patches' size making territories unable to maintaining populations (Fahrig, 2003) or the increase in the number of edges, which can lead animals to spend more time in the matrix habitat and probably conduct to an increase of mortality and to consequent decrease of population's density (Debinski and Holt, 2000; Fahrig, 2003). Nonetheless, some authors assume several positive effects of habitat fragmentation. For example, it can develop the persistence of a predator-prey system, i.e. the smaller patches may work like sites of refuge for preys, where they can increase in number and then disperse to the surrounding areas (Huffaker, 1958). Habitat fragmentation which leads to spatial complexity of the environment may also foment coexistence between competitors (Levin, 1974; Slatkin, 1974).

Before the above, two primordial ideas, which promoted the hypothesis' formulation of this work, should be retained:

1) Spatial complexity may stimulate coexistence between competitors.

2) Habitat selection results in a crucial factor for coexistence of animals within the same trophic level.

Besides these two reflections, another one, not less important, was also referred: habitat fragmentation leads to a reduction of landscape patches' size and when these patches become too small the maintenance of populations can be compromised. This concern may evolve to another one: the hypothetical decrease in the number of individuals of a population, due to the diminution of habitat's carrying capacity. This decline can be so drastic that, in the end, may conduct to species extinction.

This was probably a recurrent reasoning made by some authors to infer that habitat destruction, or its fragmentation, are amongst the main threats to biodiversity (Wilcove et al., 1998; Debinski and Holt, 2000; Fischer and Lindenmayer, 2007). Morris (1995) states that the Earth has been suffering a profound landscape change promoted by anthropogenic factors, and currently, a main part of the surface is covered by agricultural fields and industrial forestry. In the Iberian Peninsula context, natural forest (at lower and medium-altitude dominated by oak species *Quercus spp.* (Ramil-Rego et al., 1998)) became eroded and great part of the landscape was converted into agriculture (Amo et al., 2007), as result of human settlement, 7-8 thousand years ago. The changes in landscape continued and in the last century, the remaining native forest was gradually replaced by faster growing and economically profitable species, more precisely the maritime pine *Pinus pinaster* Aiton. and eucalyptus *Eucalyptus globulus* Labill. (Paiva, 1998; Vieira et al., 2000). In Central Portugal, and according to the last National Forest Inventory (2007), the role of these two species in soil occupancy is quite expressive, occupy 48,2% and 30,4% of forest territory, respectively (DGRF 2007).

In theory, the effectiveness of an habitat is determined by organisms' response, being the most suitable the one where survival and reproductive success are higher (Orians and Wittenberger, 1991).

Hence, the main objectives of this study were:

- To evaluate and describe habitat selection patterns by three sympatric carnivores (red fox, common genet and stone marten) within a fragmented landscape, and discuss about the habitat requirements of each species.

- To analyze and discuss the interspecific interactions resultant from the coexistence of the three carnivore species, based on ecological parameters such as niche breadth and niche overlap, and infer about competition processes that may be occurring.

- To infer about the adequacy of current land-uses and the effect of habitat fragmentation in the study area in terms of biodiversity conservation, taking into account that the obtained results refer to three predator species, located at the upper layers of the local food chains.

- To assess the impact of large monocultural stands and local current forestry practices on carnivores' distribution and abundance, by contrasting species occurrence in those plantations (maritime pine and eucalyptus stands) and in old-growth, very diverse woodland (Bussaco National Forest).

- To conjecture about the effects of human presence and perturbation over the referred carnivore species, analyzing their occurrence in habitats with great levels of anthropogenic activity (urban and agricultural areas).

In order to achieve these objectives, a research was developed, as described in the paper that constitutes chapter 3, which is the center of the entire thesis. This article holds the core of this thesis, summarizing all the work carried out.

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2. Study area

2.1. Location

Study area is located in “Beira Litoral” province, Center of Portugal, inside a latitudinal interval between 40˚18’13’’ and 40˚27’15’’ North and an interval of longitude between 8˚19’46’’ and 8˚25’15’’ West. It includes territories belonging to five municipalities: Anadia, Mealhada, Mortágua, Penacova and Coimbra from three districts: Aveiro, Viseu and Coimbra in a total 16 470 hectares area. Bussaco National Forest is located in the center of the study area (Figure 1).

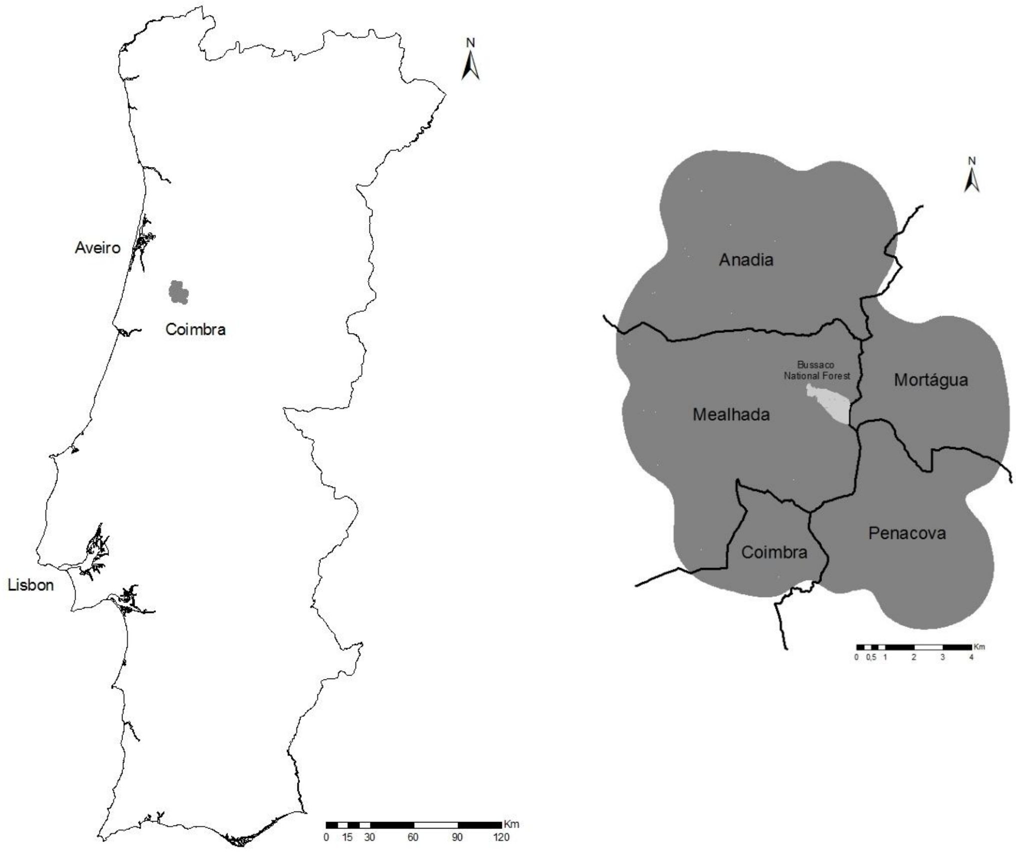

Fig. 1. Study area location in Central Portugal. Municipalities comprehended in the study area.

2.2. Land cover

The Central region of the country, according to the National Forest Inventory 2005/2006 (DGRF, 2007), has the following cover pattern: forest area - 973 500 ha, agricultural area - 572 400 ha, urban - 99 700 ha, shrub areas - 668 900 ha and interior waters - 29 000 ha. Inside forest area, the large part consists of maritime pine *Pinus pinaster* Aitton which together with *Pinus pinea* L. occupy a 415 100 thousand ha area. The second species with the largest area within the forest area is *Eucalyptus globulus* Labill., occupying an area of 258 400 ha and only 93 100 ha is occupied by deciduous trees, including *Quercus* spp. as the oaks, holm oaks, cork oaks and chestnut *Castanea sativa* Mill.

Oak species, in the past, represented the main tree cover in that region (Ramil-Rego et al., 1998). With Iberian human occupancy, 7-8 thousand years ago, native vegetation was being eroded and great part of the landscape was converted to agriculture. The land-use alterations continued and in the last century, the remaining native forest was gradually replaced by faster growing and economically profitable species, precisely the maritime pine and eucalyptus (Paiva, 1998; Vieira et al., 2000).

Within the study area, with no exception, a large part of the occupation belongs to the eucalyptus trees and after that the resinous (Table 1). There is also a considerable extent of cultivation land where traditional agriculture is carried out, with small vegetable-gardens, marshes with cereals and fallow land; and agriculture for commercial purposes, more intensive and machine-labored. In that fields the main crops are corn *Zea mays* L., bean, such as *Phaseolus* spp., grape *Vitis vinifera* L., mostly for wine production, olive *Olea europea* L., potato *Solanum tuberosum* L., fruits (apple *Malus* spp. and *Citrus* spp., for example) and several vegetables as cabbage *Brassica oleracea* L., lettuce *Lactuca sativa* L. and tomato *Lycopersicum esculentum* Mill.. Inside the study area there is also a percentage in order of 0.63% occupancy by the Bussaco Forest, with a distinct classification from others because of the peculiarity of his mixed woodland.

Table 1. Area and percentage of each land-cover class in the study area and comparison with Central Portugal.

	Study area		**Central Portugal**
Land cover class	**Area (ha)**	**Percentage**	**Percentage**
Agriculture	4519.63	27.43%	27.16%
Eucalyptus	6969.81	42.31%	12.26%
Deciduous trees	150.20	0.91%	4.42%
Shrub	373.56	2.27%	31.74%
Resinous trees	3579.44	21.73%	19.70%
Urban	777.20	4.72%	4.73%
Bussaco Forest	104.06	0.63%	
TOTAL	**16473.90**	**100.00%**	**100.00%**

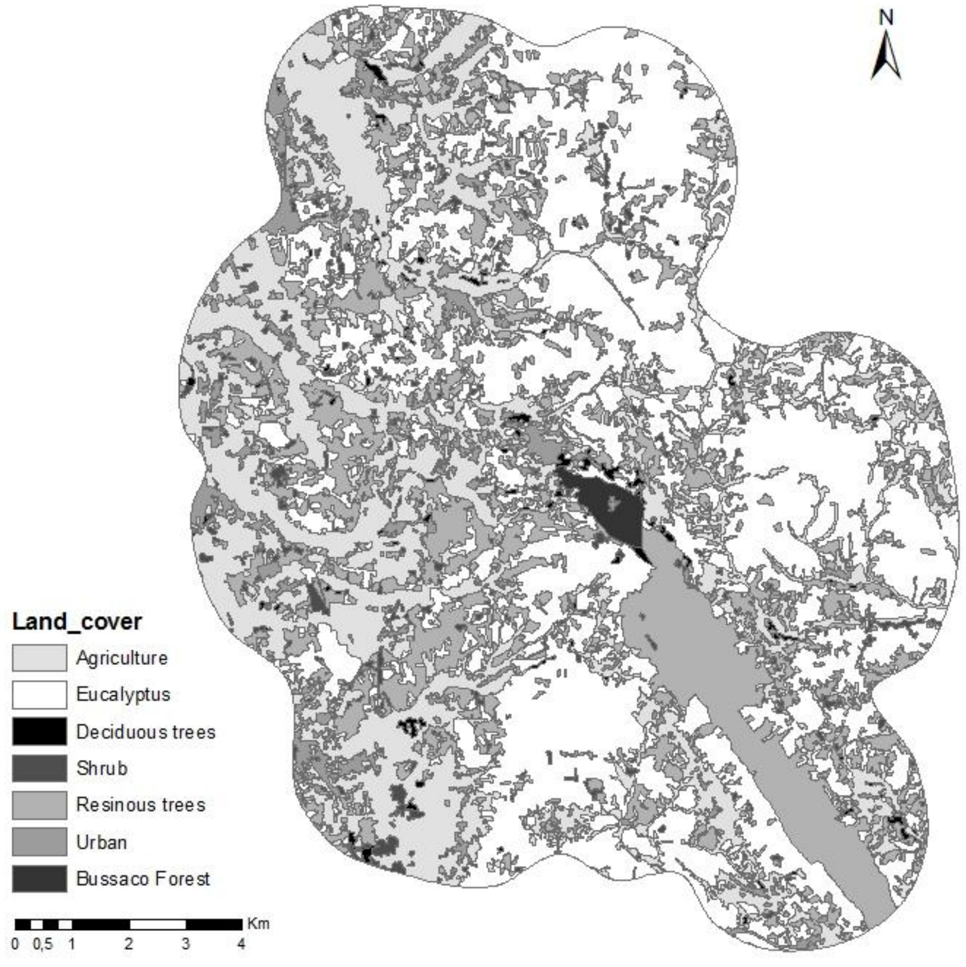

Fig. 2. Land-cover map of the study area (situated between 40˚18’13’’N - 40˚27’15’’N and 08˚19’46’’W - 08˚25’15’’W.

The study area includes “Serra do Bussaco”, a mountain with a general NW-SE orientation, which constitutes the most relevant relief element of the landscape. The highest altitude situates at “Cruz Alta” (547 m.a.s.l., 40°22’13’’N, 8°21’59’’W), at the northwestern far side of the mountain and at the center of the study area. Serra do Bussaco includes Bussaco National Forest and presents a large extension of *Pinus pinaster* mostly planted in the first half of the 20th century (Morais, 2002). The remaining middle and low-raised relief terrains in the study area are, in general, covered by *Eucalyptus globulus* plantations, mostly planted since the second half of the last century (Radich, 2007). These lands belong to private owners that plant even-aged eucalyptus stands for the paper production industry, clear-cutting them totally when the desired size is achieved (approximately 8 years).

2.3. Bussaco National Forest

Bussaco Forest represents a singular woodland, historical, cultural and religious heritage. It is located roughly in the center of the study area, between 40°22'15'' and 40°23'01'' N latitude and between 8°21'26'' and 8°22'30'' W. It is an area of about 105 ha, bounded by a wall of approximately three meters in length of 5750 m all around. The altitude of the forest is included in a range between 190 m and 547 m, and Cruz Alta its highest point. There are ten gateways to the interior of the forest, and the road that traverses the entire length of it, connecting the ports of Ameias, Serpa and Rainha, through which flows a large amount of cars daily, with higher intensities in the summer.

Bussaco Forest belongs to the locality of Luso, Mealhada municipality and district of Aveiro. Recently the Bussaco Forest Foundation was established, under the Law N. 120/2009 of 19th May, constituting the entity now responsible for the management and administration of the Forest.

The vegetation legacy of Bussaco Forest includes, according to Paiva (2004), one of the best tree collections in Europe. It started being planted with exotic species mostly in the 17th century, by friars of the Discalced Carmelites order, who owned the land at the time.

The friars introduced several exotic species, such as the Mexican cypress *Cupressus lusitanica* Miller, which is nowadays the most abundant tree in Bussaco. Another substantial amount of exotic tree species, from the entire globe, was planted after 1856, under state administration (Paiva, 1992). Pinho et al. (2009) have recently been studying Bussaco's flora and vegetation and point out the great botanical diversity of this forest, totalizing 257 tree and shrub species, organized in four major botanical ensembles:

- The arboretum, that occupies around 80% of the Forest area, presenting an exceptional tree diversity and dozens of "remarkable specimens" (classification due to their size, age, national rarity or singularity).

- Climax vegetation of Cruz Alta, locating at the highest part of the Forest (and of the study area), represents a remnant of local native vegetation from before human occupancy (Santos, 1993). The most common species are *Phillyrea latifolia* L., *Arbutus unedo* L., *Laurus nobilis* L., *Ilex aquifolium* L. and several *Quercus* spp. This vegetation covers around 17.5ha.

- "Pinhal do Marquês", occupying about 13ha. The dominant species is the maritime pine *Pinus pinaster*.

- The Gardens, "Vale dos Fetos" and "Vale dos Abetos", occupying 6.4ha. The Gardens encircle a luxurious 19th century hotel. In Vale dos Fetos, many tree ferns *Dicksonia antarctica* Labill. can be found.

This mixed forest is a markedly different and biologically rich landscape element in the study area, which, as previously described, is mainly covered by agriculture fields and monoculture plantations. Despite its reduced area, in this geographical context, Bussaco's diversity provides potential ecological value and importance. Therefore, it constitutes an independent land cover class in this study.

2.4. Biogeography

Biogeographically, the study area locates at the transition zone of two major biogeographic regions from the Holarctic kingdom: Euro-Siberian Region and Mediterranean Region. More specifically, at the junction zone of the Province Cantabro-Atlântica, subsector Miniense and the Province Gaditano-Onubo-Algarviense, subsector Beirense Litoral (Costa et al., 1998).

The association of this location with the respective confluence of two different macrobioclimates (Temperate and Mediterranean), results in a particular microclimate (see Climate section) that favors the occurrence of high floristic diversity. Hence, spontaneous vegetation of Serra do Bussaco presents deciduous vegetation, characteristic from temperate climate on the North-facing slopes, and evergreen vegetation, typically Mediterranean, on the South-facing slopes (Costa et al., 1998).

2.5. Climate

The study area situates at a transition zone of two major macrobioclimate types: Temperate and Mediterranean, receiving influences from both.

According to national meteorological reports (Meteorologia, 2007), the year of 2007 presented very low precipitation values, being categorized as extremely dry. In terms of air temperature, 2007 presented a slightly higher annual mean temperature than the 1961-90 mean value. 2008 was sorted as a dry to very dry year (with a rainy Spring, though), with temperatures vaguely lower than the mean values (Meteorologia, 2008). In terms of precipitation, 2009 was labeled as dry to normal. In Central Portugal, there was a drought situation between March and November, but December was very rainy (precipitation 60% higher than mean values). Mean annual temperature of 2009 was 0.5°C higher than 1971-2000 mean values (Meteorologia, 2009). A summary of local's climate parameters is presented on Table 2 and Figure 2.

Table 2. Climate parameters in the study area (2007, 2008 and 2009 SNIRH, 2010; Weather Underground, Inc, 2010).

	Parameter	Occurrence	Value
Temperature	Annual mean temperature	-	15.4°C
	Hottest month (average)	August	21.1°C
	Coldest month (average)	December	9.8°C
	Absolute maximum temperature	30 July 2007	39°C
	Absolute minimum temperature	9 January 2009 and 20 December 2009	-1°C
Precipitation	Mean annual rainfall	-	804.3mm
	Rainiest month (average)	December	120.9mm
	Driest month (average)	August	11.03mm
	Rainiest month in the interval	January 2009	209.9mm
	Driest month in the interval	August 2009	6.0mm
Relative humidity	Mean annual relative humidity	-	65.0%
	Moistest month (average)	January	74.1%
	Driest month (average)	March	58.8%

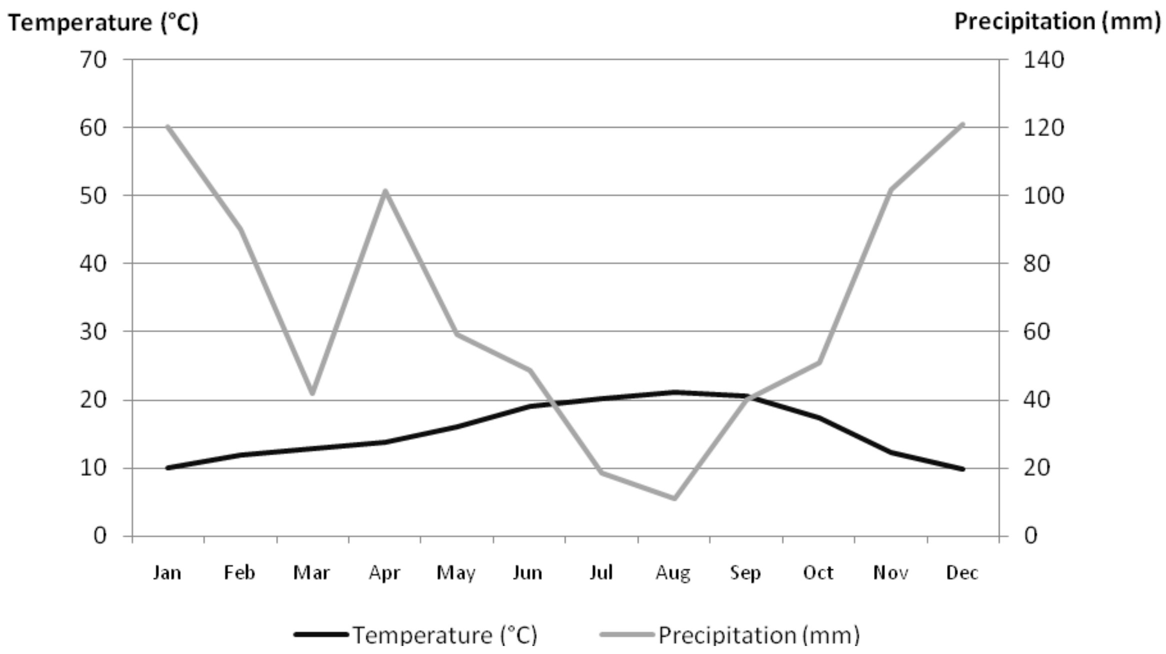

Fig. 3. Climate chart of study area (2007, 2008 and 2009).

It must be highlighted that Bussaco National Forest, due to its particular location and *sui generis* vegetation presents a microclimate quite different from the rest of the study area. In relation to the general study area, Bussaco presents a fresher and rainier climate, with larger amplitude of temperature. A meteorological station was functioning in the Forest (altitude 381masl) between 1926 and 1942 (Santos, 1993), yet the gathered data still constitute a good approximation to current conditions.

2.6. Lithology

The lithology of the study area, namely of Serra do Bussaco, has been well studied and cartographed by several researchers, since 1853. Further and more complete descriptions can be consulted, for example, on Costa (1950), Young (1988), Sequeira and Medina (2004) and Flores (2010).

In a general way, the study area comprises terrains of the Meso-Cenozoic margin on the western half and of the “Maciço Marginal” (geomorphological unit of the Iberian massif) on the eastern half. The Meso-Cenozoic margin is constituted by post-Paleozoic terrains, with less than 248 millions of years. The Iberian massif includes the oldest terrains, from Paleozoic and Precambrian, very deformed, with some depressions filled with more recent deposits (Sequeira and Medina, 2004).

The oldest formations are sedimentary and metamorphic rocks, from Cambrian to Precambrian (including *Schist-Greywacke* Complex). Serra do Bussaco encompasses terrains with different ages that belong to a formation called “Bussaco syncline”. This structure extends from Bussaco National Forest for 40km, until “Penedos de Góis”, in Serra da Lousã and includes *sedimentary and metamorphic rocks such as* metasandstones, carbonated rocks, metapelites and conglomerates. The most recent outcrops of Serra do Bussaco (silicified sandstones) date from the Cretacic period and compose the “grés do Bussaco”.

The western part of the study area includes several sedimentary formations (such as alluvial deposits, sands, conglomerates, limestone, clay deposits) dated from between the Jurassic period and the Holocene time (Agência Portuguesa do Ambiente, 2010*a*).

2.7. Soil

The study area includes three major types of soil: Cambisols, Podzols and Litosoils. The greater part of the study area is covered with Humic Cambisol developed over schist or schist and quartzite. Adjacent to these territories, Chromic Cambisols can be found and in the western part of the study area locate Ortic Podzols associated with Calcaric Cambisols (Agência Portuguesa do Ambiente, 2010*b*).

In the southern part of the study area and in less significant extents situate Eutric Cambisols (post-Paleozoic sedimentary rocks), Calcic Cambisols and Eutric Litosoil associated with Luvisoil (Agência Portuguesa do Ambiente, 2010*b*).

2.8. Hydrography

The study area comprises watercourses from two hydrographic basins: those of Vouga and Mondego rivers. In the northwestern part of the study area, all thalwegs drain to Cértima river, which is a left tributary of Vouga river. In the south-eastern part of the study area, thalwegs drain to Mondego’s affluents or bayous.

Not all watercourses in the study area are permanent. A great part of small creeks only carry water during the rainiest season of the year.

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3. Habitat selection by sympatric red fox (*Vulpes vulpes*), common genet (*Genetta genetta*) and stone marten (*Martes foina*) in a rural landscape

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3.1. Abstract

Understanding distributional patterns and habitat selection mechanisms of species is crucial in order to adopt effective land management policies, in terms of biodiversity conservation. A heterogeneous landscape may generate coexistence, although it depends always of habitat efficacy. We aimed to study habitat selection, niche breadth and niche overlap of three sympatric carnivores in a typically fragmented landscape of central Portugal, using camera-trapping techniques. The results showed that species use the available habitats differently and in a non random way, presenting preference and avoidance trends. The red fox was the species which presented the most specialized behavior, positively selecting coniferous forests. The common genet preferred eucalyptus, avoiding Bussaco forest, old-growth mixed woodland, in contrast with stone marten which showed strong preference for the latter, avoiding the eucalyptus. Using the Standardized Hurlbert's niche breadth, the genet has the highest (0.734) and red fox the lowest (0.442). At station level, niche overlap was superior between the genet and the stone marten (0.413 - Piankas's index) which suggests that these species can coexist in the same area and share some common resources. At the habitat level, the greatest niche overlap was presented by the stone marten and the red fox (0.909), indicating that they largely exploit the same general habitat conditions, however, at a local scale, resource partitioning should occur (0,288). Our study reinforces the concept that landscape complexity allows coexistence between species within the same trophic level.

Key-words: habitat selection, camera-trapping, sympatric carnivores, niche breadth, niche overlap

3.2. Introduction

Habitat destruction and fragmentation has been pointed out as the main threat to biodiversity (Wilcove et al., 1998; Debinski and Holt, 2000). Anthropogenic and natural causes induce a change in the availability of habitats, and consequently the proportion of individuals of a certain species in a particular habitat type, may be altered. Thus, population size and growth may vary with the proportion of distinct habitat type's availability (Pulliam and Danielson, 1991). Habitat selection may be described as the behavior of a given species, mediated by biotic and abiotic factors, that determines environment effectiveness for that species. In theory, the effectiveness of a habitat is determined by organisms' response, being the most suitable the one where survival and reproductive success is higher (Orians and Wittenberger, 1991). Therefore, the study of habitat selection patterns of certain organisms may be crucial to understand which environmental variables influence the fitness of individuals and the viability of populations (Sarmento et al., 2010).

Habitat fragmentation implies several phenomena that consist not only in the reduction of habitat amount (habitat loss) and patches' size but also in the increase of habitat patches number and isolation (Fahrig, 2003), which also alters the properties of the remaining habitat (van den Berg et al., 2001).

In the Iberian Peninsula, natural forest (at lower and medium-altitude dominated by oak species *Quercus* spp.(Ramil-Rego et al., 1998)) has been eroded and great part of the landscape was converted into agricultural fields (Amo et al., 2007), as result of human settlement, 7-8 thousand years ago. The alterations in landscape continued and in the last century, the remaining native forest was gradually replaced by faster growing and economically profitable species, more precisely the maritime pine *Pinus pinaster* Aiton. and eucalyptus *Eucalyptus globulus* Labill. (Paiva, 1998; Vieira et al., 2000). In Central Portugal, and according to the last National Forest Inventory (2007), the role of these two species in soil occupancy is quite expressive, occupying 48.2% and 30.4% of forest territory, respectively.

The common genet *Genetta genetta* L., the red fox *Vulpes vulpes* L. and the stone marten *Martes foina* L. are three abundant carnivores of the Iberian fauna, considered of "low concern" in conservation terms (Cabral et al., 2005). Despite their sympatry, they show distinct patterns of habitat use. Whereas the common genet has been described to occur predominantly in areas with considerable tree and shrub densities (Palomares and Delibes, 1994; Virgós et al., 2001; Galantinho and Mira, 2009), the red fox presents a generalist/opportunistic behavior in habitat use, showing activity in agricultural fields like vineyards and olive-yards (Lucherini et al., 1995) or areas with dense forest cover generally selecting heterogeneous areas (Cavallini and Lovari, 1994; Cagnacci et al., 2004). The stone marten seems to be a generalist species too (Virgós and García, 2002; Santos and Santos-Reis, 2010), occurring in cork woodlands, riparian vegetation, pasturelands, orchards (Santos and Santos-Reis, 2010) as in other cultivated fields like olive-yards and vegetable-gardens (Santos-Reis et al., 2006) and scrubs (Rondinini and Boitani, 2002).

Spatial complexity of the environment may foment coexistence, being habitat selection one of the main processes that allows that phenomena (Rosenzweig, 1981). Different patches in landscape support a set of resources allowing sympatry of species in the same trophic level (Levin, 1974) and enhance the persistence of predator-prey interaction (Fahrig, 2003). Interactions within the same trophic level should be favored when species with different selective behavior coexist (Pimm and Rosenzweig, 1981; Rosenzweig, 1987). In other words, cohabitation in a fragmented habitat is privileged when there are species which select space in a frequent/exclusive way (specialist) and species selecting space not in such a specific way (generalist).

In our study, we aimed to expand the pre-existent knowledge concerning the mechanisms responsible for the selection of habitat types and the co-existence of the sympatric red fox, the common genet and the stone marten, focusing on the following aspects: i) density and habitat selection among the different landscape units present in the studied rural landscape; ii) niche breadth of each species and iii) niche overlap between the three species. Furthermore, the adequacy of current land-use policies in Portugal will be discussed, in the scope of carnivore and overall biodiversity conservation.

3.3. Materials and methods

Study area

The study area is located in Central Portugal, nearly between 40˚18’13’’N - 40˚27’15’’N and 08˚19’46’’W - 08˚25’15’’W. It is centered in the Bussaco National Forest (altitude between 190 m and 547 m.a.s.l.), a wall fenced 105 ha old-growth mixed woodland, which represents, according to Paiva (2004), one of the best dendrological collections in Europe. This forest started being planted during the 17th century and some of the most representative species of trees and shrubs are *Cupressus lusitanica* Mill., *Quercus robur* L., *Q. pyrenaica* Willd., *Q. suber* L., *Castanea sativa* Mill., *Laurus nobilis* L., *Arbutus unedo* L., *Viburnum tinus* L., *Ilex aquifolium* L, *Ruscus aculeatus* L., *Phillyrea latifolia* L., *Prunus laurocerasus* L., *Pittosporum undulatum* Vent. The climate of the study area is predominantly Mediterranean, although with some Atlantic influences, thus hot summers (maximum 39˚C) and mild winters (minimum -1˚C) occur. Annual average rainfall is about 804 mm, mostly concentrated in autumn and winter. Nevertheless, the Bussaco Forest presents a microclimate particularly fresh and rainy, being its annual precipitation of around 1525 mm.

The Land-cover of the study area is quite heterogeneous. Large extensions of monocultures of eucalyptus (42.31%) and pine (21.73%), agricultural fields (27.43%), urban areas (4.72%), shrubs (2.27%), deciduous trees (0.91%) and Bussaco forest (0.63%) feature that mosaic.

From the total 16470 ha area, previously defined to line-transect surveys of field signs, three sampling sub-areas were selected (A, B and C) (figure 4), totalizing 1545 ha of effectively sampled area, which was calculated using a buffer of 600 m radius (Sarmento et al., 2010) around each trap station, assuming that each camera location corresponds to the centre of the animals’ home range.

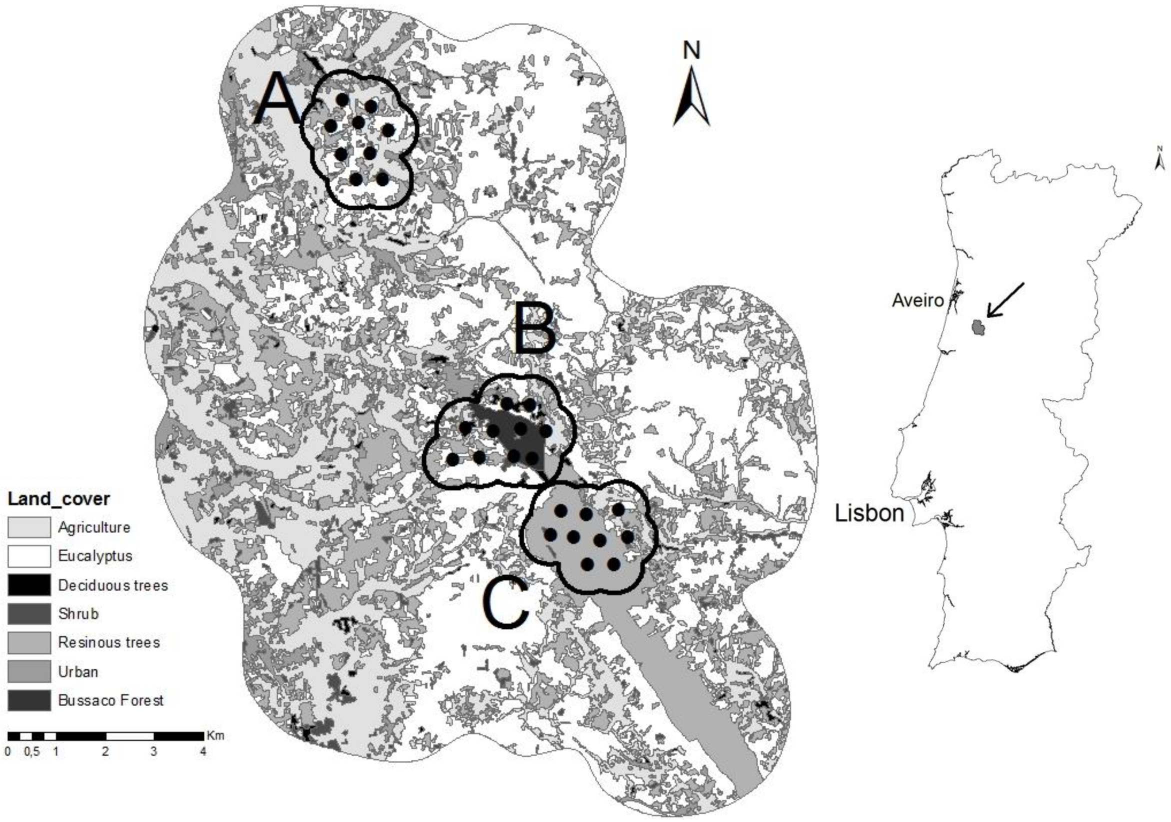

Fig. 4. Location of the study area in mainland Portugal, location of the three sampling sub-areas and land cover map of the study area.

Habitat classification

The three sub-areas were established according to land-cover characteristics, being sub-area A dominated by eucalyptus, sub-area B by mixed forests (Bussaco Forest included) and zone C by coniferous trees, namely maritime pine. In all three zones little and isolated patches of urban tissue and agricultural fields occur.

A GIS database for the study area was built to delineate soil use classes, using ESRI® software ArcGIS 9.3. Based on aerial photos, field surveys and COS 90 (land-cover shapefile produced by Instituto Geográfico Português CNIG, 1995) six land-cover units were recognized: Agricultural fields (traditional and more intensive agriculture, where the main crops are corn *Zea mays* L., bean, such as *Phaseolus* spp., grape *Vitis vinifera* L., olive *Olea europea* L. and potato *Solanum tuberosum* L.); Eucalyptus forest (*Eucalyptus globulus*); Coniferous forest (mainly *Pinus pinaster* but also *Pinus pinea* L.); Broadleaves forest (mostly oak species: pedunculate oak *Quercus robur* L., holmoak *Quercus rotundifolia* Lam and cork oak *Quercus suber* L.; but also other deciduous trees such as chestnut *Castanea sativa* Mill.); Urban areas and Bussaco Forest.

Camera-trapping surveys

Field work was carried out between 15th June and 13th September 2010. Each sub-area was surveyed for an exact 30 days period (30 trap-nights).

10 Bushnell® Trophy Cam were used, set to a time interval of one second and to take three photos at every contact. The date, time, temperature and lunar phase were shown labeled in all photos. The sensitivity level chosen was “normal” or “low” depending on the sun and heat exposure of each trapping-station. Each camera was charged with a 2 Gb SD card that allows to store about 1900 photos (8 Mp resolution), which corresponds to 633 shots approximately, and eight alkaline batteries that, according to the manufacturer, provide six month of continuous work.

Cameras were placed at a height interval of 15 cm to 25 cm and at a 2 m (aprox.) distance from the lure. Sand with domestic cat urine and canned sardines were used as lure in all trap-stations. The lure was replaced and the SD cards were emptied every three days (Kauffman et al., 2007). Vegetation within field of view of the cameras was removed to avoid false shots.

Trap-stations were distributed in a grid within every sub-area, being the mean distance among nearest cameras: 601 ± 63 m for sub-area A; 594 ± 79 m for sub-area B, 585 ± 65 m for sub-area C and 594 ± 69 m overall.

A pilot campaign of 15 days was first conducted in order to assess efficiency of lures and effectiveness of cameras in the study area, time period to empty SD cards and lure replacement, battery life and technical details of cameras. All 10 cameras were used.

Individual identification of specimens

Individuals of the common genet and the red fox were identified according to guidelines of other mammal studies using photo individual identification (Jackson et al., 2006; Sarmento et al., 2009; Sarmento et al., 2010) considering pelage patterns, body marks (ear cuts, scars, broken tails, etc.) and biometric parameters. Photos with distorted perspectives, which lacked clarity not allowing to understand pelage patterns or any other particular mark, were not considered for individual recognition. Specimens' identification was not conducted for the stone marten due to lack of singular characteristics of individuals.

Data analysis

In order to determine the demographic closure of the population under analysis, we used the method of Stanley and Burnham (1999). The abundance estimates of the red fox and the common genet were made using the maximum-likelihood estimator in Capture software and following the procedure of Otis et al. (1978). After testing for all possible models (which assumed different sources of variation operating in the probability of capture), the null model was selected as the best-fitting model in all cases.

To analyse the patterns of habitat selection exhibited by the red fox, the common genet and the stone marten (preference or avoidance of each habitat type), we calculated the selection ratios and Bonferroni-adjusted 95% confidence intervals for each habitat type, as described by Manly (2002). The selection ratio (w_{ij}) was calculated as:

$$w_{ij} = \frac{o_{ij}}{\pi_{ij}}, \qquad \text{eqn 1}$$

where o_{ij} is the proportion of observation in the habitat i and π_{ij} is the proportion of habitat i available for species j . A selective use of habitat occurred when w_{ij} differed statistically from 1 (P<0.05). If w_{ij} was significantly higher than 1 preference occurred, if significantly lower than 1 avoidance happened. The standard error (SE) of the selection index was:

$$SE\,(w_{ij}) = \sqrt{\frac{o_{ij} \cdot (1-o_{ij})}{u_{ij} \cdot \pi_{ij}^{2}}}, \qquad \text{eqn 2}$$

where u_{ij} was the total number of observations. The standardized selection ratios ($B_{w_{ij}}$) were used for direct comparisons between selection ratios and calculated as:

$$B_{w_{ij}} = \frac{w_{ij}}{\sum_{i=1}^{I} w_{ij}} \;. \qquad \text{eqn 3}$$

A log-likelihood chi-square test (χ_L^2) was used to test the null hypothesis that carnivores were randomly using all habitat types in proportion to its availability.

Using the observed distribution of the species within the set of habitat types, we calculated the niche breadth of each carnivore according to the Hurlbert method (Hurlbert, 1978):

$$H'_j = \frac{1}{\sum_{i=1}^{I} \frac{o_{ij}^{2}}{\pi_{ij}}}, \qquad \text{eqn 4}$$

that takes the availability of the resources into account. H' was standardised to H'A:

$$H'_{A_j} = \frac{H'_j - \pi_{i_{min}}}{1 - \pi_{i_{min}}}, \qquad \text{eqn 5}$$

which ranges from 0 (strong preferences for some resources) to 1 (no preferences for any resource) and where $\pi_{i_{min}}$ is the smallest proportion of all the habitats.

The overlap in the resource use among the three carnivores was measured at two different scales (i.e. station and habitat scales) through the Pianka's index of niche overlap (Pianka, 1973):

$$O_{jk} = \frac{\sum_{i=1}^{I} o_j \cdot o_k}{\sqrt{\sum_{i=1}^{I} o_j^2 \cdot \sum_{i=1}^{I} o_k^2}}, \qquad \text{eqn 6}$$

that is a symmetric measure of overlap between species j and k and ranges between 0 (no resources used in common) to 1 (complete overlap).

3.4. Results

Population density estimates

The global population density estimates were 1.49±0.16 red fox km^{-2} and 1.17±0.08 common genet km^{-2}. Depending on the habitat type which dominates each sub-area, species have higher or lower density estimates. The sub-areas B and C arise as the regions of higher densities of both red fox and common genet. In the case of stone marten, it was impossible to estimate the population size due to methodological constrains. However, considering linearity between the number of photographs and the number of animals, sub-areas B and C also come up as regions with high densities of carnivores (Table 3).

Table 3. Number of photos, population estimates and capture probability of red fox, common genet and stone marten in the three sub-areas of the study area.

	Red fox			***Common genet***			***Stone marten***		
	Number photos	*Estimate population	Capture probability	Number photos	*Estimate population	Capture probability	Number photos	*Estimate population	Capture probability
Sub-area A	4	1 ± 0.1 (1.0-2.0)	0.500	25	6 ± 0.8 (6.0-9.1)	0.361	7	-	-
Sub-area B	30	8 ± 0.9 (8.0-12.0)	0.354	11	10 ± 4.8 (6.0-45.4)	0.133	114	-	-
Sub-area C	117	8 ± 0.6 (8.0-10.1)	0.417	43	8 ± 0.9 (8.0-12.0)	0.354	202	-	-

*estimate abundance ± standard error (95% confidence interval). – not estimated due to methodological constrains.

Habitat selection

The selection ratios obtained for each carnivore species show that the habitat types were not randomly selected (red fox: $\chi_L^2{}_{(5)}$=170.47, *P*<0.001; common genet: $\chi_L^2{}_{(5)}$=34.26, *P*<0.001; stone marten: $\chi_L^2{}_{(5)}$=163.56, *P*<0.001). Indeed, the results expressed in table 4 illustrate a positive selection of coniferous forest and a significant avoidance of eucalyptus forest and humanized areas (agricultural fields and urban areas) by the red fox. Relatively to common genet, the eucalyptus forest arises as the preferred habitat, while Bussaco forest and the humanized areas are avoided by this species. For stone marten, the high positive selection of Bussaco forest and coniferous forest contrasts with an avoidance similar to that observed for red fox (Table 4).

Table 4. Habitat selection ratios by the red fox, common genet and stone marten.

	Red fox		***Common genet***		***Stone marten***	
	Selection ratios*	*P*	Selection ratios*	*P*	Selection ratios*	*P*
Bussaco forest	0.927 ± 0.227	0.748	0.354 ± 0.201	**0.001**	2.196 ± 0.220	**<0.001**
Broadleaves forest	1.298 ± 0.479	0.534	0.709 ± 0.495	0.556	0.520 ± 0.210	0.534
Coniferous forest	2.642 ± 0.123	**<0.001**	0.930 ± 0.174	0.689	1.701 ± 0.097	**<0.001**
Eucalyptus forest	0.169 ± 0.052	**<0.001**	1.643 ± 0.137	**<0.001**	0.552 ± 0.058	**<0.001**
Agricultural fields	0.185 ± 0.106	**<0.001**	0.236 ± 0.165	**<0.001**	0.376 ± 0.102	**<0.001**
Urban areas	0.185 ± 0.130	**<0.001**	0.000 ± 0.000	**<0.001**	0.043 ± 0.043	**<0.001**

*Selection ratios are represented as w ± standard error. If w is significantly higher than 1 (P<0.05) occurs preference, if significantly lower occurs avoidance.

The direct comparison between the habitats selected by the three studied species, using the standardized selection ratios (Figure 5), reveals a higher selectivity exhibited by the red fox, followed by the stone marten. All the species showed different selection patterns, exhibiting different values of B_w in all the sampled habitats (Figure 5).

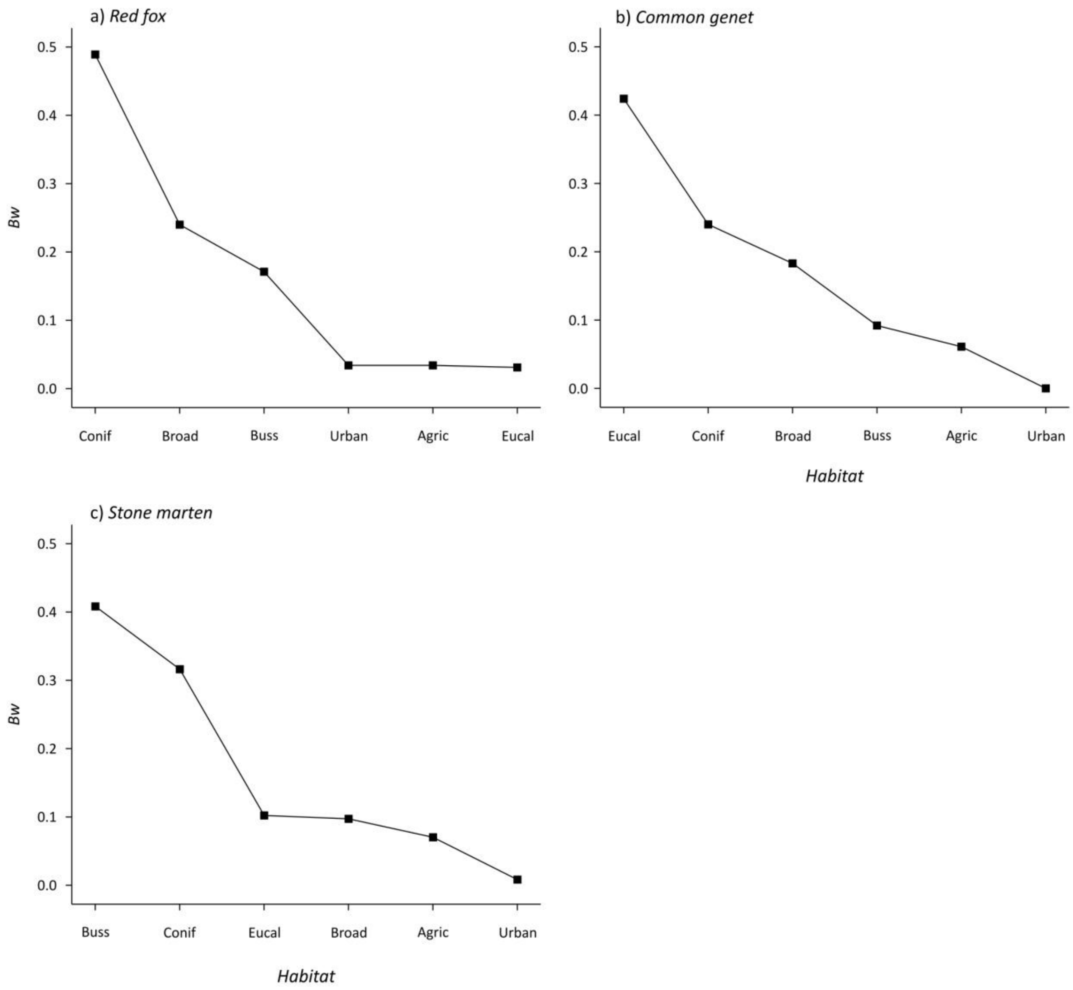

Fig. 5. Habitat standardized selection ratios profiles of red fox, common genet and stone marten, where Buss is Bussaco forest, Broad is broadleaves forest, Conif is coniferous forest, Eucal is eucalyptus forest, Agric is agricultural fields and Urban is urban areas.

Niche breadth and niche overlap

Standardized niche breadth, H_A, differ among the studied species, being more similar between the common genet and the stone marten, that present a more generalist behaviour (higher H_A) than red fox (Table 5).

Table 5. Standardized Hurlbert's niche breadth for the three carnivore species.

	Red fox	*Common genet*	*Stone marten*
Niche breadth	0.442	0.734	0.660

In terms of niche overlap, the results indicate a higher overlap between the common genet and the stone marten at station level, but at the habitat level the maximum overlap occurs among the red fox and the stone marten (Table 6). The lower values for overlap obtained at the station level indicate that an additional spatial segregation is occurring at a finer scale than that of the habitat level.

Table 6. Pianka's index of niche overlap among the three carnivores, calculated at two different spatial scales.

	Red fox *vs* Common genet	Red fox *vs* Stone marten	Common genet *vs* Stone marten
Station level	0.116	0.288	0.413
Habitat level	0.464	0.909	0.684

3.5. Discussion

Understanding distributional patterns and habitat selection mechanisms of carnivores, species located at the highest levels of food chains, may be essential to build effective land management policies, where biodiversity conservation is a keystone.

Due to methodological constraints, it was not possible to individualize the trapped stone martens. Thus, individualization was only performed for the red fox and the common genet, allowing to estimate species density in each sampling area. An overview to the calculated carnivore densities revealed generally low values, however higher than those presented in other studies carried out in the Iberian Peninsula (Palomares and Delibes, 1994; Sarmento et al., 2009; Sarmento et al., 2010). Higher densities of a certain species in a particular habitat may suggest a greater carrying capacity, thus, an improved quality, revealing to be more suitable for that species.

It is clear that the three studied species use the available habitats differently and in a non random fashion, showing preference and avoidance trends. The red fox preference for coniferous woodlands was already reported by Cavallini and Lovari (1991) and Goldyn (2003) referred that this species foraged mainly in more open habitats where rodents are abundant, as small mammals, namely *Apodemus sylvaticus* L., constitute foxes' main prey (Serafini and Lovari, 1993; Carvalho and Gomes, 2004). We can assume that trend as analogous to the one occurring in our study area, as the coniferous forest shelters a considerably density of *A. sylvaticus* (Matos et al. in prep.) and, in spite of being a forest habitat, it is industrially managed to produce timber, so it does not have a great tree or understory density. Among the woodlands present in our study area, coniferous are the most open ones. In addition, the resinous forests present a large and continuous extension, allowing the red fox a higher occurrence (Virgós et al., 2002). We hypothesize that non-selectivity of Bussaco forest, the habitat with the highest *A. sylvaticus* abundance, can have two non-exclusive explanations: i) the little patch size of Bussaco forest (105 ha) which can disable the settlement of a red fox population (Virgós et al., 2002), attending to this species' need of large areas (Cavallini and Lovari, 1994; Lucherini and Lovari, 1996); ii) Bussaco forest presents very dense and cluttered arboreal and shrubby vegetation, conditioning predation process by reducing prey's accessibility.

The Common genet showed positive selection for eucalyptus and avoidance of Bussaco forest, which was a quite unexpected result. However, it is known that the genet has large flexibility in terms of habitat choice (Calzada, 2002), since dense shrub cover, great availability of food (namely *A. sylvaticus*, its main prey Palomares and Delibes, 1988; Palomares and Delibes, 1994; Virgós and Casanovas, 1997) and low risk of predation are provided (Palomares and Delibes, 1994; Virgós and Casanovas, 1997; Virgós et al., 2001;

Virgós et al., 2002; Zabala et al., 2009). In this case, these ecological requirements are all fulfilled, as eucalyptus stands of the study area present considerable understory cover (e.g. *Erica spp.*, *Ulex spp.*, *Rubus spp.*), that allow rest and refuge sites for genets, prey abundance (Matos et al, in prep), and low occurrence of red fox (as shown in the results), a potential predator. Bussaco forest also presents the mentioned conditions, though i) as previously hypothesized for the red fox, the fragment size may constitute an important constraint for the occurrence of carnivores with a large home range, particularly if the area approximates to 100 ha (Virgós et al., 2002); ii) Bussaco presents old arboreal vegetation, giving a dense cover of large and elevated branches. We hypothesize this arrangement allows an arboreal behavior by the genets, which may reduce their soil activity and condition their occurrence in the cameras.

The stone marten was the only carnivore that positively selected Bussaco forest, along with coniferous. Bussaco represents an old-growth forest with an exceptional structural complexity where martens can find a wealth of resources to exploit. Natural cavities, understory density and diversity of trees with well-developed foliage that provide refuge and rest sites. Being stone martens feeding generalists (Such and Calabuig, 2003; Santos and Santos-Reis, 2010) able to exploit the vertical and horizontal components of the habitat, due to their arboreal behavior (Padial et al., 2002), they find in Bussaco great diversity of feeding items: high density of small mammals (Matos et al, in prep), fruit (e.g. *Prunus laurocerasus* L., *Arbutus unedo* L., *Rubus spp.*, *Pittosporum undulatum* Vent.), arthropods, etc. Principally during summer (Lanszki et al., 1999), fruit constitutes a main item in stone martens' diet (Brangi, 1995; Santos-Reis et al., 2005) and amongst forested habitats of the study area, Bussaco detains the highest fruit availability and diversity, which should influence the stone martens' selectivity towards this woodland. We presume the second habitat preference is also related to food availability, although in this case, mainly small mammals (Matos et al, in prep.). Despite of the red fox's risk of predation in the coniferous forest, stone martens can minimize it by using vertical component of the habitat. Notice that *A. sylvaticus* is also mentioned as having arboreal habits (Montgomery, 1980; Rosalino et al., 2010). The avoidance of eucalyptus plantations may be related to the presence of other competitors, namely the common genet, that may restrict stone martens' distribution (Santos and Santos-Reis, 2010).

The three sympatric species showed consistent avoidance for highly humanized land-cover units: agricultural fields and urban areas. Representing the study area a rural landscape, in a smallholdings basis, the aforementioned anthropized habitats reveal elevated levels of human activities, pressure and perturbation. Furthermore, a great number of domestic animals, such as dogs, occurs, and those are reported to attack some medium-sized carnivores (Palomares, 1990; Palomares and Delibes, 1994). Altogether, these factors can justify the described avoidance.

Besides habitat selection, niche breadth and overlap constitute crucial parameters to completely understand the ecosystem's functioning. An overview to the niche breadth results indicates a higher habitat specialization by the red fox, which may be due to general low population densities within the study area. In other words, a low number of individuals in the study area diminishes the need of the red fox to exploit less favorable habitats, becoming more specialized in the most suitable one. It is well established that when a population reaches the carrying capacity of the habitat, species tend to become more generalist (Hanski et al., 1991). In agreement with the previously analyzed results, the common genet presents the highest niche breadth, using a greater number of habitats.

The different results obtained with the two scale approaches, station and habitat level, justified the need to calculate niche overlap by the two manners. A first look at table 6 allows us to verify the generally greater niche overlap at habitat level in comparison to station level, as expected. In terms of habitat level, since the dominant habitats of the study area present large patch sizes, it is unavoidable that carnivore species coexist in them. On the other hand, the lower results obtained for niche overlap at station level suggest that resource partitioning is occurring in a finer scale, as this measure may illustrate a more direct competition.

The Red fox and common genet's niche overlap, at both levels, suggests these species are direct competitors, avoiding each other and not sharing common resources (niche segregation). As stated before, red fox prefers more open spaces where it can move and forage more easily (Cavallini and Lovari, 1994; Lucherini and Lovari, 1996). The genet showed preference for eucalyptus, a habitat with dense understory that provides refuge and prey (*A. sylvaticus*) abundance. In relation to red fox and stone marten, the results concur with what was previously discussed. There is a very extensive habitat use overlap, suggesting the exploitation of the same physical space, though at local level few common resources are used. This may corroborate the explanation of the stone marten's ability to use the vertical component of environment, hence segregating from the red fox resources. Stone martens and common genets exhibit a considerable niche overlap at habitat and station level, which suggests that they can coexist in the same space and share some resources. This should be due to the elusive character of both species (Thompson, 2004), reflected by their need of refuge (understory).

This study demonstrates that ecologically similar species may coexist in the same geographic region, being favored by landscape complexity, translated by habitat diversity. At a larger scale, species cohabit in the same habitats, whereas locally they use resources differently, reducing overall competition.

Our results and the obtained densities in particular, reinforce the established concept that unreserved territories also play an important role in biodiversity conservation, as natural reserves alone will not be able to effectively do so (Franklin, 1993; Fischer et al., 2006).

From a conservationist perspective, we cannot affirm that habitat fragmentation and monocultural exploitations are presenting negative effects over the studied carnivore community. Nevertheless, it must be highlighted that eucalyptus stands must maintain some structural complexity, that is, a preserved understory layer, in order to sustain or promote the analyzed populations, specially the common genet. Also, the occurrence of different carnivore populations is possible due to the presence of large patches of different forest habitats, with sufficient area to allow species' settlement.

Further studies involving variables at an even finer scale, testing the influence of locally more precise variables, and eventually including more target species, should reveal profitable to better understand the ecosystem's dynamics and functioning, and helpful to suggest more effective land-use/forestry management strategies for overall biodiversity conservation.

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4. Main conclusions

First of all, this study reinforces that camera-trapping is a practical and time-efficient method which allows studying elusive species in a non-invasive way. In other words, the use of camera-trapping permits the assessment of population and ecological parameters such as density or breadth niche that would require expensive and time-consuming methods to obtain otherwise, with minimal habitat or wild population's perturbation. Therefore, camera-trapping constitutes a highly recommendable method for habitat selection or other distributional studies of carnivores. Nevertheless, it must be referred that the success of the method depends largely on the correct camera lodgment and handling. Similarly as performed in this study, it is recommended to perform a pilot-campaign to correctly adjust cameras' functioning and placement details.

Yet regarding the applied methodology, using several target species and two scale approaches, it proved to be very important to better understand the ecology and general scenario concerning the carnivore community of the study area. Attending to the obtained results, a single-species research could lead to erroneous conclusions about habitat preferences, if that species was studied as a surrogate for carnivore community.

It was demonstrated that the typical complexity of Central Portugal's landscape, resultant from the large monoculture forest extensions and smallholdings basis of urban planning, is promoting co-existence of several species among carnivore trophic level. Extrapolating, it is presumable that in this geographical region, landscape heterogeneity constitutes a key-factor to sustain communities' diversity and abundance, contributing to overall biodiversity conservation. Notwithstanding, caution must be taken when assuming that, in this case, fragmentation and monocultural exploitations are not presenting negative effects over the studied carnivore community. From a conservationist perspective, habitat fragmentation, constituting landscape complexity, is favoring species co-existence and abundance. However, this is possibly because there is also some structural complexity within habitats, allowing several ecological opportunities (feeding, refuge, etc.) and because some patches present areas sufficiently large to permit the settlement of these medium-sized mammals. So, patch size and habitats' quality (related to the ecological opportunities provided) are playing a major role in this particular case. Similar caveats should be presented when affirming that, in the study area, monocultural stands are not negatively affecting the carnivores' community. Forestry practices may not be as injurious to biodiversity as it is commonly assumed, provided that some requirements are fulfilled, namely the maintenance of within-stand complexity.

The generality of this study's results and the obtained densities in particular, point out the importance of unreserved matrix for biodiversity conservation, reinforcing the soaring concept that natural reserves alone will not be able to effectively preserve the whole of natural heritage. As shown, human activities may not necessarily be detrimental for biodiversity. In certain cases, the adoption of some simple measures can conciliate nature preservation with anthropogenic procedures, as long as there is the knowledge necessary to correctly instruct the competent authorities and the general population.